OXYGEN ISOTOPE CONTRAINTS ON THE SOURCES OF OCEAN ISLAND BASALTS

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Oxygen isotope ratios in phenocrysts from ocean island basalts (OIB) can place constraints on the origins of their mantle sources. Values of $\delta^{18}O$ in olivines from alkali basalts from Pitcairn Island (which have the extreme "EM1" signature based on radiogenic isotopes) are equal to those of olivines from average mantle peridotite (based on studies of mantle xenoliths and the MORB source region) . This result suggests that the amount of recycled continental sediment in Pitcairn Island EM1 sources is less than ~0.75%. Based on studies of olivine phenocrysts, the sources of both the plume component of Hawaiian lavas and of all measured Juan Fernandez ("PHEM") samples also have oxygen isotope compositions indistinguishable from average upper mantle peridotite. If these OIB sources come from the lower mantle, it is implied to have an oxygen isotope ratio similar to the upper mantle. Low $^{18}O/^{16}O$ olivines from some Hawaiian lavas are associated with a more MORB–like He and radiogenic isotope component, possibly recycled but also consistent with contamination from the base of the modern Pacific plate.

INTRODUCTION

Oxygen isotope ratios in mantle–derived lavas can provide important constraints on the nature and origin of mantle reservoirs. Due to the large ^{18}O–enrichments (or depletions) caused by weathering (or high–temperature water/rock interaction), $\delta^{18}O$ can be a sensitive indicator of crustal and surficial processes. For this reason, oxygen isotopes can help to discriminate between models for the genesis of OIB source regions; e.g. between enrichments caused by intramantle metasomatism and by recycling of crustal sediments. We present here the results of measurements of oxygen isotope ratios of phenocrysts from basaltic rocks from four 4 OIB volcanic centers (Pitcairn, Hawaii, Juan Fernandez, and Gambier). These place constraints on the origins of the "EM1" (enriched) and "PHEM" (primitive, high $^3He/^4He$) mantle end members, and preliminary information on the sources of lavas carrying highly radiogenic Pb[1].

ANALYTICAL TECHNIQUE

Approximately 5–20 mg of olivine and/or plagioclase (ca. 10–20 fragments) were separated from samples by hand–picking under a binocular microscope (after crushing, washing and sieving), preferentially choosing fragments with the smallest contents of visible inclusions and alteration. Mineral separates were analyzed by laser fluorination at the University of Wisconsin[2]. The mean and standard deviation (1σ) for a Gore Mountain garnet standard (UWGMT-2) analyzed concurrently with samples was 5.74±0.07 (n=35), within uncertainty of the accepted value of $\delta^{18}O_{SMOW}$=5.8±0.1. The average deviation from the mean of replicated analyses (±0.06‰) is comparable to this nominal precision, suggesting that oxygen isotopic variability between grains within a given sample is minimal (each analysis is of 1–5 grain fragments). Multiple analyses of fragments from a single grain of San Carlos olivine yielded a $\delta^{18}O$ value of 5.25±0.07‰ (n=13), comparable to the average of ~5.2 for olivine from mantle peridotite xenoliths[3].

PITCAIRN

The Pitcairn hotspot (southeast Pacific Ocean) carries the strongest EM1 signature known in oceanic lavas, and this characteristic is found in rocks from both Pitcairn Island and from the nearby Pitcairn seamounts[4]. Oxygen isotope ratios of olivine phenocrysts from 8 samples are within analytical uncertainty of each other, averaging 5.21±0.08‰ (Figure 1). Plagioclase $\delta^{18}O$ values (n=5; 4 from rocks in which olivine was also analyzed) average 6.05±0.15‰, resulting in a plagioclase/olivine fractionation equal to the expected magmatic value (~0.9–1.0‰ for An_{65} at 1100–1200°C[5]), suggesting that olivine and plagioclase were in isotopic equilibrium at magmatic temperatures.

The average $\delta^{18}O$ value of 5.21±0.08‰ for Pitcairn Island olivine phenocrysts is indistinguishable from the average value for olivine from xenoliths of mantle peridotite[3] (5.19±0.14‰), 0.5‰ lower than the average for mid–ocean ridge basalt (MORB) glasses[6] (5.7±0.2‰), consistent with the fractionation between olivine and basaltic liquid previously estimated in experimental and natural studies[7], and equal to the $\delta^{18}O$ value of olivine in lunar basalts[8]. Pitcairn island olivines are therefore indistinguishable in their oxygen isotope ratio from the best estimates of olivines in the upper mantle and the bulk mantle. These results strongly suggest that the enriched EM1 mantle source sampled by Pitcairn Island basalts contains little, if any, directly added ^{18}O–rich sediment (≤0.75% if sediment is assumed to have a $\delta^{18}O$ value of 25‰).

Submarine glasses from the Pitcairn seamounts have been reported to have high $\delta^{18}O$ values (up to 6.8–7.4‰); these have been interpreted as evidence of subducted sediments in the EM1–rich mantle sources of these lavas[9], inconsistent with our results. Many of the seamount samples are chemically evolved, and major element composition is highly correlated with radiogenic isotope ratios (i.e., the chemically evolved end member is associated with the EM1 signature[4]). Values of $\delta^{18}O$ in evolved oceanic magmas are often elevated by 0.6–1.5‰ above values in related basalts, consistent with isotopic fractionation during melting or crystallization[10]. Mixing between an evolved, high-$\delta^{18}O$, EM1 end member and alkali basalts having less of the EM1 signature can explain both the chemical and isotopic variations in the Pitcairn seamounts .

HAWAII

Hawaiian lavas are consistently low in $\delta^{18}O$ relative to most other OIB[11] (the only comparable volcanic center is Iceland, where ^{18}O depletion is associated with melting and assimilation of hydrothermally altered crust[12]). The fact that low $\delta^{18}O$ values and high $^3He/^4He$ ratios are both observed in Hawaiian lavas has led to the hypothesis that ^{18}O–depletion relative to the MORB source region is either a general feature of the undegassed lower mantle, or of the portion of the deep mantle sampled by the Hawaiian plume[10].

We have analyzed oxygen isotope ratios in phenocrysts (principally olivine) from over 80 samples of Hawaiian lavas in order to constrain the source of the ^{18}O–depleted signature. Values of $\delta^{18}O$ in olivine phenocrysts are correlated with whole rock radiogenic isotope ratios, such that samples containing olivine with $\delta^{18}O$ values in the range of the mantle average (~5.2) are associated with high $^3He/^4He$ and more "enriched" or "primitive" Nd and Sr isotope ratios, while olivines from lavas having more MORB–like radiogenic and He isotope signatures are low in $\delta^{18}O$ (down to 4.6‰). This relationship is most clearly expressed in plots of $\delta^{18}O$ vs. radiogenic isotope ratios for samples of Mauna Loa and Mauna Kea from the Hawaiian Scientific Drilling Project core (Figure 2). Low $\delta^{18}O$ values (<5.0‰) are almost exclusively found in olivines from "Kea trend" volcanoes (Haleakala, Kohala, Mauna Kea, Kilauea), the only exception being the most recent historic Mauna Loa lavas. These results suggest that the Hawaiian plume (with its high $^3He/^4He$ more "enriched" or "primitive" radiogenic isotope ratios) is indistinguishable in $\delta^{18}O$ from the upper mantle/xenolith average, and that anomalous, low $\delta^{18}O$ values are only seen when this plume component has been diluted by a more depleted reservoir. This depleted reservoir is plausibly associated with hydrothermally altered lower oceanic crust, possibly recycled but also consistent with contamination from the base of the modern Pacific plate.

JUAN FERNANDEZ

The Juan Fernandez islands (south Pacific) contain basalts and basanites having Nd and Sr isotope ratios covering a relatively restricted range (ε_{Nd} =+3.3–4.9; $^{87}Sr/^{86}Sr$ = 0.7034–0.7037), but a wide range of $^3He/^4He$ ratios (18.0–7.8 RA), interpreted to reflect mixing between a plume component from a primitive, undegassed reservoir ("PHEM")[1], and an asthenospheric or lithospheric component, dominantly represented in the post–shield lavas[13]. Olivines from lavas carrying both signatures are similar in $\delta^{18}O$, the entire population averaging 5.1±0.1‰ (n=9), consistent with sources having oxygen isotope ratios comparable to average upper mantle peridotite. Olivines from basanites are slightly ^{18}O enriched relative to those from transitional and alkali basalts (by ~0.2‰), possibly reflecting chemical and/or temperature dependent fractionations during melting and magmatic evolution. The Juan Fernandez samples represent an important complement to the Hawaiian lavas we have studied, in that both suites contain shield–building basalts with elevated $^3He/^4He$ ratios. The observation that both island groups contain a plume component with a $\delta^{18}O$ value in the range 5.1–5.3‰ suggests that the relatively "primitive", undegassed mantle sampled in plumes is not significantly different in oxygen isotope ratio from the average shallow mantle sampled by MORB and peridotite xenoliths.

GAMBIER

Olivines from two samples of alkali basalt from Gambier islands, southeast Pacific ocean, have been analyzed. Both have $\delta^{18}O$ values of 5.2‰. Although only two samples have been analyzed, these results are significant because they contain the most radiogenic Pb of any samples described in this study ($^{206}Pb/^{204}Pb$ > 19), and therefore may provide constraints on the origin of the "HIMU" component, which has been suggested to be associated with recycled oceanic crust[14]. Values of $\delta^{18}O$ in these two samples are consistent with derivation from sources with $\delta^{18}O$ values indistinguishable from average upper mantle peridotite xenoliths and the MORB source; in particular, they suggest that the sources of these lavas do not contain significant quantities of low–$\delta^{18}O$ hydrothermally altered lower oceanic crust or high–$\delta^{18}O$ upper crust and sediments. The presence of a mixture of the two components having the average MORB oxygen isotope composition cannot be excluded.

1: Zindler and Hart, Annu. Rev. Earth Planet. Sci. (1986); Farley et al., EPSL (1992) **2**: Kohn et al., Am. Mineral. (1993) **3**: Mattey et al., EPSL (1994) **4**: Woodhead et al., EPSL(1989); Woodhead & Devey, EPSL, (1993) **5**: Chiba et al., GCA, (1989) **6**: Ito et al., Chem. Geol. , (1987) **7**: Anderson et al.,J. Geol. (1971); Muehlenbachs & Kushiro Carnegie Inst. Washington Yearb. , (1974); Kyser et al., CMP, (1981) **8**: Clayton et al., Proc. Second Lunar Sci. Conf., (1971) **9**: Woodhead et al., Nature, (1993) **10**: Matsuhisa, Y. J. Volcanol. Geotherm. Res., (1979); Muehlenbachs & Byerly, CMP, (1982); Sheppard & Harris, CMP, (1985); Weis et al., EPSL (1987) **11**: Kyser et al., CMP, (1982); Garcia et al., JGR, (1989); Garcia et al., JGR, (1993) **12**: Sigmarsson et al., CMP, (1992); Hemond et al., JGR, (1993) **13**: Farley et al., CMP, (1993) **14**: Hart, EPSL (1988); Weaver, Geology (1991)

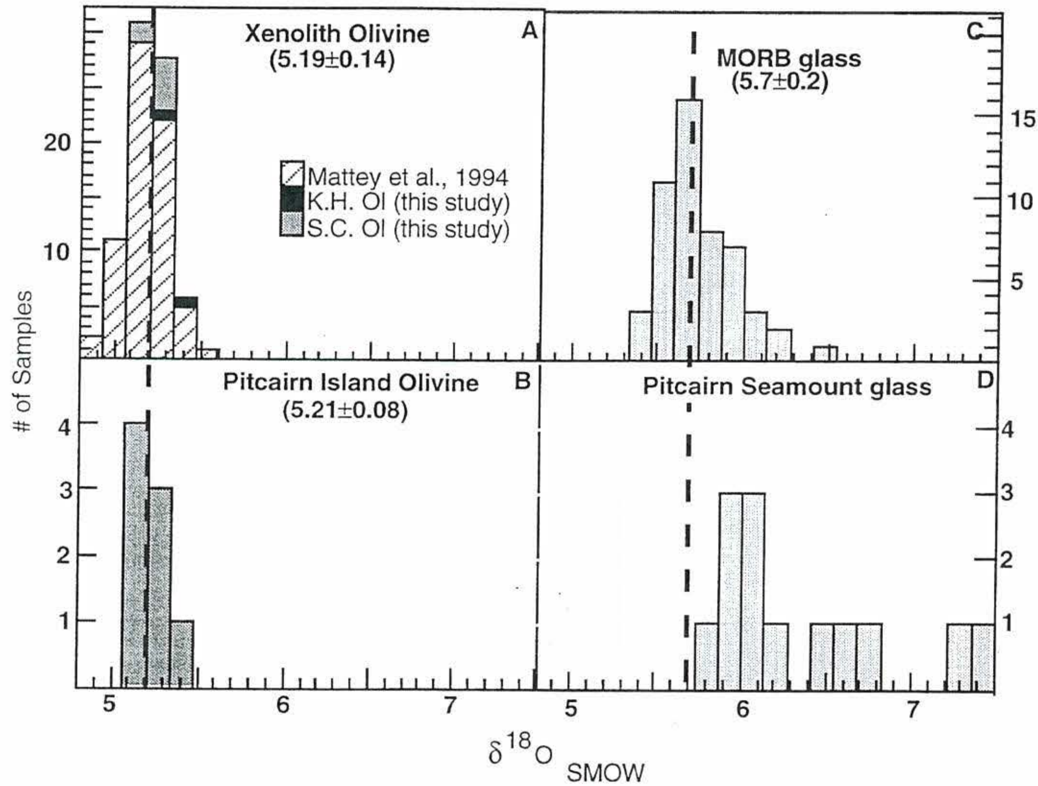

Figure 1: Histograms of $\delta^{18}O$ values. (a) Olivine from mantle xenoliths; (b) olivine phenocrysts from Pitcairn Island alkali basalts (this study; each sample is counted only once, i.e., multiple analyses of olivines from a single sample have been averaged); (c) basaltic glasses from a world-wide sampling of MORBs; and (d) basaltic–to–evolved glasses from the Pitcairn seamounts[9].

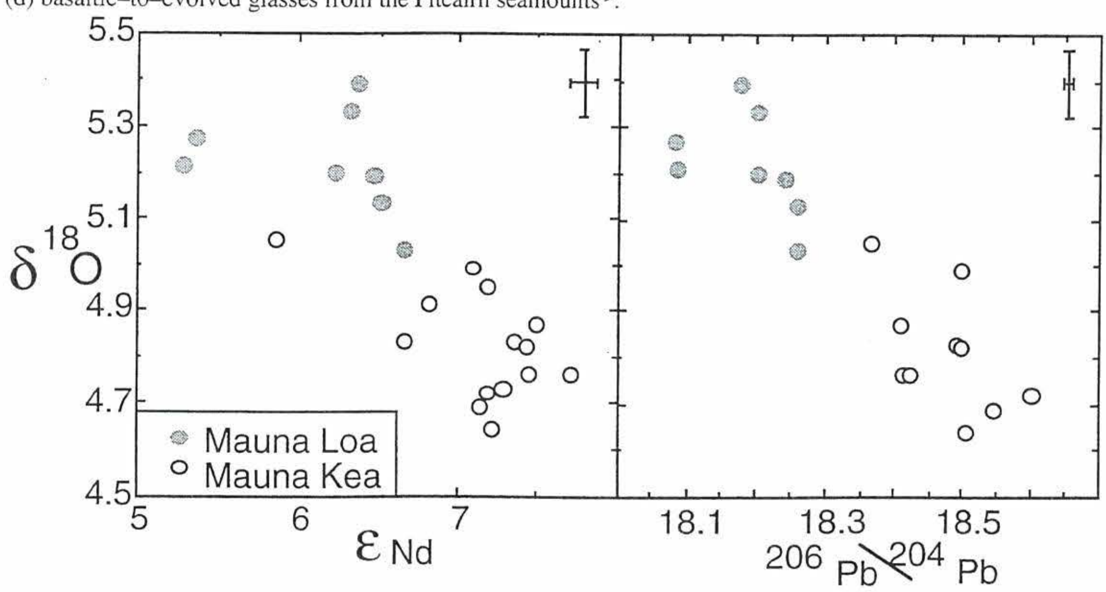

Figure 2: Values of $\delta^{18}O$ measured in olivine from lavas from the Hawaiian Scientific Drilling Project core and related samples, plotted vs. whole rock radiogenic isotope ratios (reported by Hofmann et al., Lassiter et al., and Kurz et al., JGR in review). Low–$\delta^{18}O$ Mauna Kea samples have $^3He/^4He$ and radiogenic isotope ratios characteristic of a more MORB–like source than the Hawaiian plume.

PLUME 2

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